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Vision Based Global Navigation System for Autonomous Urban Transport Vehicles in Outdoor Partially Known Environments

Miguel Angel Sotelo*
Department of Electronics
University of Alcalá

Luis Magdalena
Department of Mathematics
Technical University of Madrid

Francisco Javier Rodríguez
Department of Electronics
University of Alcalá

Luis Miguel Bergasa
Department of Electronics
University of Alcalá

Abstract

This paper describes a vision-based system for autonomous urban transport missions in outdoor environments. Specialized modules are implemented for particular tasks such as lane tracking and navigation along crossing points. A system that can execute a complex mission cannot simply be the sum of its perceptual modalities, and so, there needs to be a "plan" which uses high level knowledge about goals and intentions to direct the behaviors of the low level perception and actuation modules. The system presented in this work undertakes the challenge of getting a real robot to work in the real world, in real time.

1 Introduction

One of the most challenging issues in the field of autonomous navigation is unmanned transport in outdoor environments. For many years, researchers building mobile robots have concentrated on applications involving hazardous environments. It has been clearly stated in the last years that one of the mos hazardous environments is the automobile expressway. Our aim is quite different indeed. In this work we undertake the challenge of intelligent unmanned mission execution for transport applications in suburban areas (industrial areas, university campus, etc) using a single video camera and a cheap GPS receiver.

Early in the development of unmanned ground vehicles, it became apparent that some form of mission execution and monitoring was needed to integrate the capabilities of the perception systems. A lane follower alone has no way to know which way to turn at an intersection, no way to know when to speed up or slow down for important events, etc. On the other hand, the system should take advantage of the performance of a robust lane follower, just to track the lane, not to perform any other task. This yields to the concept of specialized efficient tasks that must be joined together by some consistent control architecture.

There are two main requirements for autonomous robot navigation in outdoor environments. First, vision based tasks must be able to operate on very different suburban scenarios. That constitutes a complex problem to tackle with. Second, the overall system must be fast enough to drive the vehicle at normal speeds (e.g., 40 km/h on urban areas). That's the main rationale for the real-time approach. These requirements put severe constraints on the type of algorithms and operating systems that can be used.

2 Previous work

Previous works apply vision-based techniques for detecting certain characteristics in the image like, for instance, lanemarks[2]. Others are based on color or texture[8] features. An alternative approach considered in the NAVLAB project in the Carnegie Mellon University combines vision and learning techniques (neurally inspired) to compute the characteristics that properly describe the path along the road[5]. Included in the Prometheus III project (EUREKA programme) of the European Community[2], a Mercedes 5000 SEI car (VaMoRs-P) was equipped with a complex sensor system (4 color cameras, three inertial sensors, etc) and a sophisticated processing system (60 transputers and several PC 486's) with the aim of driving the vehicle along motorways at high speed. Within the PATH[4] programme in the American State of California, with the support of

*Escuela Politécnica. Campus Universitario. Alcalá de Henares. Madrid. Spain. E-mail: sotelo@depeca.alcala.es

the Institute of Transportation Studies of the University of California in Berkeley, extensive work has been carried out since 1986 on autonomous vehicles steering. Magnetic sensors buried under the road are used to facilitate lateral control of the vehicle along with a radar for obstacles avoidance. Also in the Carnegie Mellon University the so called "SAUSAGES"[7] control architecture was developed and tested on unmanned ground vehicles both at Carnegie Mellon and at Lockheed Martin. Systems using SAUSAGES for task management have driven ground vehicles on missions of some kilometers using a mix of road following (particularly on highways and cross country areas), obstacle avoidance, and remote teleoperation. At the Hiroshima City University a method of route description[6] has been developed based upon iconic and geometrical information. A mobile robot moves in an environment consisting of routes and intersections, represented by a graph-like description. A route map including both iconic and geometrical information can be built by fusing the camera and GPS information, and used for further robot localization.

3 Overall Architecture

The system is intended to receive missions specifications and is implemented on an autonomous mobile robot (electric car) that performs those missions in a partially known environment, in particular, the Campus of the University of Alcalá and the private circuit in the IAI (Instituto de Automática Industrial) of the Spanish CSIC. All modules on board the robot make use of the same description of the environment for several purposes dealing with mission specification and robot navigation.

Environment Model This environment model has been designed to enable the implementation of the mission execution system. The model is a topological and geometrical representation of the environment. An environment is a topological graph of routes and crossings or intersections. The routes are composed of lanes that have an exclusive direction. The real environment may also contain unknown obstacles/objects which have to be taken into account on-line by the robot to provide detection and avoidance if possible.

Robot Missions The goal of this project is to provide an autonomous transportation system for students in the Campus of Alcalá, as it is the largest in Spain. Basically, the robot has to plan the shortest route to the destination station, making use of the environment model, and coordinate the resulting plan by dividing the execution into several vision based specialized tasks.

Robot Control Architecture The Robot Control Architecture includes all functional modules (GPS, motors drives, dead reckoning, etc), two vision based specialized tasks, for routes and crossings respectively, as well as the global planner and execution supervisor, as depicted in figure 1.

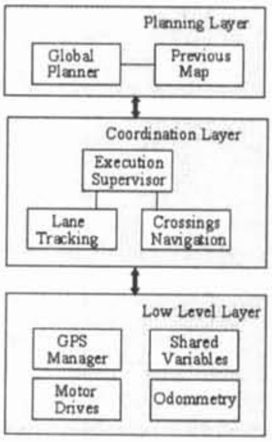


Figure 1: Robot Control Architecture.

4 Vision Based Specialized Tasks

The system exploits the efficiency of particular processes in specialized tasks, that must be joined together by an execution supervisor to decide which task is active at each moment, according to the plan, the environment model and the GPS information. Two main tasks have been developed.

Lane Tracking The mission of this task is to provide correct lane tracking between two consecutive crossings. It implies an ambitious goal in a complex and non structured outdoor environment. The following situations make it hard to perform in the real world: parked cars might appear on both sides of the street, zebra crossings coud interfere the segmentation, pedestrians crossing the street must be respected, etc. The lane tracker we propose deals with this complexity to some extent, relying on a potential field approach [1]. The incoming image is resampled by hardware building a low resolution image of what we call the Area Of Interest (AOI). The AOI comprises only a squared area of the image (not the whole image) as depicted in figure 2. Looking too far away makes no sense as it is too soon to react now, while looking too close to the vehicle is not necessary as there is no time to react. That's the main rationale to focus on the central area of the image.

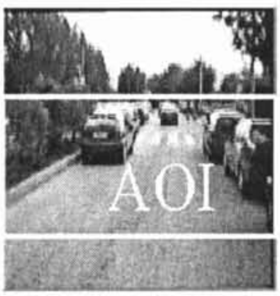


Figure 2: Area of Interest.

The AOI is segmented basing on color properties. The proposed segmentation relies on the HSI (hue, saturation, intensity) color space because of its close relation to human perception of colors. The hue component represents the impression related to the dominant wavelength of the color stimulus. The saturation corresponds to relative color purity. Colors with no saturation are grey-scale colors. Intensity is the amount of light in a color. In contrast, the RGB color space has a high correlation between its components (R-B, R-G, G-B)[3]. In terms of segmentation, the RGB color space is usually not preferred because it is psychologically non-intuitive and non-uniform. The scheme performs in two steps:

1. Pixels are classified as chromatic or achromatic as a function of their HSI color values: hue is meaningless when the intensity is extremely high or extremely low. On the other hand, hue is unstable when the saturation is very low. According to this, achromatic pixels are those complying with the conditions specified in equation 1.

$$I > 90 \; or \; I < 10 \; or \; S < 10 \tag{1}$$

where the saturation S and intensity I values are normalized from 0 to 100.

2. Pixels are classified into road and non road. Chromatic pixels are segmented using their HSI components: each pixel in the low resolution image is compared to a set of pattern pixels obtained in the first image in a supervised manner. The distance measure used for comparing pixel colors is a cylindrical metric. In previous research, it has been found that the cylindrical distance metric is superior over other well known distance measures. It computes the distance between the projections of the pixel points on a chromatic plane as defined in equation 2.

$$d_{cylindrical}(s,i) = \sqrt{(d_I)^2 + (d_{ch})^2} \tag{2}$$

with

$$d_I = \mid I_s - I_i \mid \tag{3}$$

and

$$d_{ch} = \sqrt{(S_s)^2 + (S_i)^2 + 2S_sS_i cos\Theta} \tag{4}$$

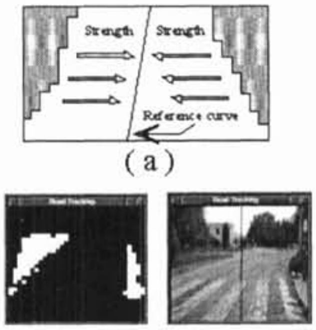
where

$$\Theta = \begin{cases} \mid H_s - H_i \mid if \mid H_s - H_i \mid < \pi \\ 2\pi - \mid H_s - H_i \mid if \mid H_s - H_i \mid > \pi \end{cases} \tag{5}$$

Subscript i stands for the pixel under consideration, while subscript s represents the pattern value. An examination of the metric equation shows that it can be considered as a form of the popular Euclidean distance (L2 norm) metric. A pixel is assigned to the road region if the value of the metric $d_{cylindrical}$ is lower than a threshold T_{chrom}. For achromatic pixels, intensity is the only justified color atribute that can be used when comparing pixels. A simple linear distance is applied in this case, so that the pixel is assigned to the road region if the difference is lower than a threshold value T_{achrom}, as equation 6 shows.

$$\mid I_s - I_i \mid < T_{achrom} \tag{6}$$

Once the segmentation is accomplished, a time-spatial filter removes non consistent objects in the low resolution image, both in space and time (sporadic noise). To obtain the turning response, the non road sections in the low resolution image are considered as obstacles that must exert a rejecting force (Potential Field Approach) on the a priori straight trajectory of the vehicle. The sum of all contributions from all obstacles yields the turning angle that commands the robot direction as depicted in figure 3. The proposed segmentation allows to detect obstacles, such as overtaking cars, pedestrians crossing the streets, etc. This information is managed on a different level of abstraction to modify the velocity profile and, in general, the vehicle behavior. For example, the vehicle should disminuish velocity (or even stop) if a pedestrian is crossing in front of it.



(a)

(b) (c)

Figure 3: (a) Potential Field Approach. (b) Segmentation of Low Resolution Image. (c) Steering angle representation.

Navigation in Intersections Intersections are conflicting and dangerous areas of the environment. To achieve correct trajectory execution, according to the global plan, the system fuses knowledge on the geometrical map, the plan under execution, and DGPS data to generate a global trajectory that should be tracked by the vehicle. This constitutes the proactive part of it, while the reactive behavior is provided basing on vision perception, using the same Potential Field-based technique described above, to detect and avoid obstacles.

5 Implementation and Results

All modules were developed in C under the Real Time Linux Operating System, running on a single PC (processing up to 20 frames/s). Figure 4 shows the turning response of the vehicle during one of its missions in a series of images where an intersection is traversed.The control system is currently being tested on a carlike robot as illustrated in figure 5, on a private test circuit in the Automation Institute of the Spanish CSIC. Overtaking manoeuvrings are intended to be carried out in the present year.

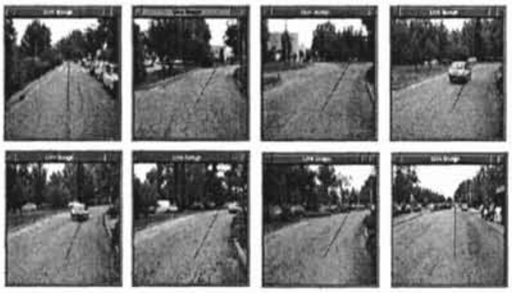


Figure 4: Example of turning response in a sequence of images.

Figure 5: Commercial prototype used for testbeds.

6 Acknowledgments

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